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Method Factors for Anemometer Measurement at Pipe Outlets

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	km/h	kilometer per hour
diam	diameter	lb/ft^3	pound per cubic foot
ft	foot	m/s	meter per second
ft/min	foot per minute	mi/h	mile per hour
ID	inside diameter	min	minute
in	inch	pct	percent
kg/m^3	kilogram per cubic meter	rad	radian

METHOD FACTORS FOR ANEMOMETER MEASUREMENT AT PIPE OUTLETS

By F. Garcia[1] and J. Cervik[2]

ABSTRACT

Gob holes are routinely used by the mining industry to vent methane from gobs and to prevent it from entering the mine ventilation system. In some cases, flows from gob holes are measured by centering an anemometer on the end of a discharge pipe. These measurements are erroneous and tend to be high by as much as 30 pct. The Bureau of Mines determined method factors (correction factors) for anemometer measurements taken in this manner.

Method factors for 4-, 6-, and 8-in (10.2-, 15.2-, and 20.3-cm) ID pipe are 0.68, 0.71, and 0.78, respectively. Comparisons between horizontal and vertical flows indicated no significant change in method factors. Consequently, the method factors for horizontal pipe flows can be applied to vertical upward flows.

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INTRODUCTION

Vertical gob holes are routinely used to control methane in gobs. In most cases, vane anemometers are used to measure the velocity of gas flowing from the gob holes and subsequently to calculate the volume flow of gas. Generally, the anemometer is centered on the end of the pipe during the measurement. If the cross section of the anemometer is appreciably larger than one-sixth of the pipe diameter, then erroneous velocity readings occur, owing to the blocking effect of the instrument (1).[3]

The pitot tube is regarded as the fundamental standard for determining velocities in ducts or piping. Generally, point traverse measurements must be made to accurately determine the average velocity and subsequently the gas flow through a pipe. These measurements are time consuming and very sensitive to gas density changes, which for a gob hole can vary from 0.042 lb/ft^3 (0.673 kg/m^3) when flow is pure methane to 0.075 lb/ft^3 (1.202 kg/m^3) when flow is all air. In addition, the accuracy of the pitot tube is limited at velocities below 1,000 ft/min (5.08 m/s) for air and 2,000 ft/min (10.16 m/s) for methane because the manometer is not precise enough to accurately measure the small velocity pressures (2).

The 4-in (10.2-cm) diam vane anemometer is an instrument commonly used by the mining industry. It is practically independent of diminutive air density changes encountered in mines and is furnished by the manufacturer with a calibration to eliminate small differences between individual anemometers, whose readings usually lie within 10 pct of the true velocity (3). These calibrations are usually in the form of tables of plus-or-minus corrections to be made to the observed velocities. The application of these corrections can be simplified by plotting the true air velocity (V_T) against the registered air velocity (V_r), which approximates a straight line. Figure 1 shows a typical calibration curve whose equation is of the form

$$V_T = A + BV_r, \tag{1}$$

where A = intercept (35),

and B = line slope or V_T to V_r ratio (0.95).

Thus, the equation for the air calibration curve is

$$V_T = 35 + 0.95\ V_r. \tag{2}$$

The calibration curve does change when the anemometer is used where there are large density changes, such as in a pure methane gas stream. The curve's slope (0.95) remains the same; however, the intercept (A) changes to

$$A = (d_a/d_g)^{1/2} \tag{3}$$

where d_a = air density at which the calibration was made (0.075 lb/ft^3 [1.202 kg/m^3]),

and d_g = density of methane (0.042 lb/ft^3 [0.673 kg/m^3]).

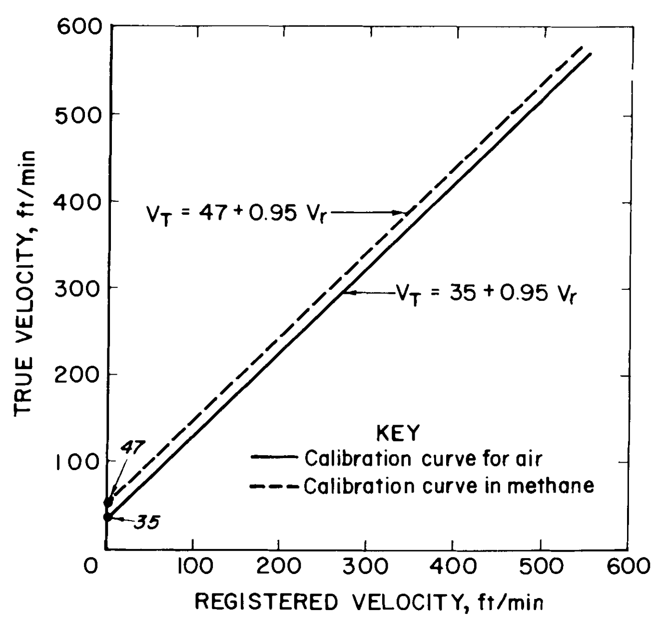

FIGURE 1.—Typical vane anemometer calibration curve.

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[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Thus, the calibration curve for a pure methane gas stream becomes

$$V_T = 47 + 0.95\ V_r. \qquad (4)$$

Figure 1 (dotted curve) shows the methane calibration curve for this particular anemometer. The difference between the two curves in this example is 12 ft/min (0.06 m/s), which is negligible where registered velocities are greater than 1,000 ft/min (5.08 m/s). For registered velocities below 1,000 ft/min (5.08 m/s), the appropriate calibration curve should be used. Where the gas flow is a mixture of methane and air, the corrected velocity can be obtained by calculating a new intercept that lies somewhere between the two curves. The slope remains the same.

The vane anemometer is normally used to make measurements in mine airways, where cross-sectional areas are much larger than the cross-section of the anemometer. Thus, the anemometer causes no appreciable obstruction to airflow. A simple and fast method used to determine the average velocity in a mine airway is to take a one-point measurement at the center of the airway. The anemometer should be mounted on the end of a short shaft with the starting and stopping done remotely to reduce measurement errors due to obstructions such as the operator's body. If the airway is straight, clear of obstruction, and has a uniform cross-sectional area, fair results are obtained after the centerline measurement is multiplied by a "method factor." A method factor becomes necessary because the velocity profile in the airway is highest at the center and decreases towards the rib, roof, and floor. Multiplying the centerline stickheld measurement by 0.85 (method factor) corrects it to the true average air velocity in the airway (4).

Very often, mine conditions prevent one-point measurements from providing accuracy. Consequently, approximate continuous traverses, made by moving the anemometer slowly through a plane at right angles to the axis of the airway, are recommended. A popular method is to divide the airway in half and traverse each half separately over a given time interval. With a little practice, this method can yield results within 5 pct of the true average velocity (3).

The National Coal Board of the United Kingdom developed method factors for correcting centerline 4-in (10.2-cm) vane anemometer measurements taken at the discharge end of pipes ranging in diameter from 12 to 30 in (30.5 to 76.2 cm) (5). The instrument was operated at the end of a rod that was held against the duct for support. It was started and stopped remotely to reduce errors caused by the operator's hand. Centerline measurements were employed because of the difficulties encountered in maintaining the alignment, position, or course of the anemometer when traversing methods were attempted. The anemometer measurements were compared simultaneously to upstream pitot-tube pipe traverses. A ratio of the true average velocity (determined from the pitot traverse) to the anemometer measurement (once corrected to its calibration) was determined for each duct size. Table 1 summarizes these method factors for each duct size.

Unfortunately, most cased gob holes in the United States are generally smaller in diameter than 12 in (30.5 cm), and the use of an anemometer to measure the velocity of flow from the end of the pipe yields erroneous volume flows. The objectives of this report are to determine the method factors for pipe sizes ranging from 4 to 8 in (10.2 to 20.3 cm) and to investigate the effect of wind speed on pipe velocity measurements by using an anemometer.

TABLE 1. - Method factors for Biran-type anemometer at the discharge end of 12- to 30-in pipe

Pipe diam, in	Velocity range, ft/min	Mean method factor	95-pct confidence limit	Pipe diam, in	Velocity range, ft/min	Mean method factor	95-pct confidence limit
12........	500-2,500	0.84	±0.05	24........	800-4,600	0.85	±0.05
18........	500-4,000	.85	±.04	30........	500-2,700	.86	±.04

TEST PROCEDURES

Figure 2 shows the general test setup used for developing the method factors. A centrifugal fan was used to induce pipe flows that were varied over a wide range with a bypass valve. Venturi tubes were employed for determining the true pipe airflows and subsequently the true mean air velocities. The airflows were calculated from static and differential pressure measurements taken with a manometer across the pressure taps of the venturi (6). The wide range of airflows investigated required numerous venturi sizes, which were interchanged in the test apparatus. A thermocouple, as required for the ASME method, was used to measure air temperatures at the venturi. The flow measurements at the venturi were then corrected to atmospheric conditions at the pipe outlet so that they could be compared directly with the anemometer readings. All anemometers employed had a calibration traceable to the National Bureau of Standards. Before direct comparisons were made, the registered anemometer readings were first corrected by using the instrument calibration curve. The effects of air density were disgarded because density variations caused less than 1 pct error.

The anemometers were operated for a 1-min period at the end of a 2-ft (61-cm) long by 5/8-in (1.6-cm) diam rod and were started and stopped by a simple remote control device (fig. 3). The rod was held against the pipe for support except on the 4-in (10.2-cm) pipe, where the instrument was held against the pipe (fig. 4). For larger pipe sizes, the anemometer was carefully positioned in the center of the airstream with the plane of vane rotation held normal to the horizontal axis of the pipe. An error of only 1 pct occurred when the plane of vane rotation was tilted as much as 20° (0.35 rad) from the normal (1).

Anemometers are normally used with the plane of vane rotation held in the vertical plane. The instruments are also calibrated in this position. Studies have shown that no large discrepancies exist between measurements of horizontal (vane rotation in vertical plane) and vertical upward (vane rotation in horizontal plane) airflows in a mine (3). Tests were conducted to confirm those results for pipe flows. The general test setup (fig. 2) was modified by adding a 90° elbow and a vertical pipe extension so that method factors could be determined for vertical upward airflows (fig. 5) and subsequently compared with the method factors for horizontal flows.

Air velocity measurements should be taken at least 7.5 pipe diameters (7.5 D) downstream from an elbow or branch entry that causes a nonuniform velocity profile in the pipe (2). Measurements taken closer than 7.5 D may be erroneous; however, the 7.5 D distance may not always be possible so measurements taken closer may be necessary. Consequently, tests were conducted to determine the effects on method factors when measurements at

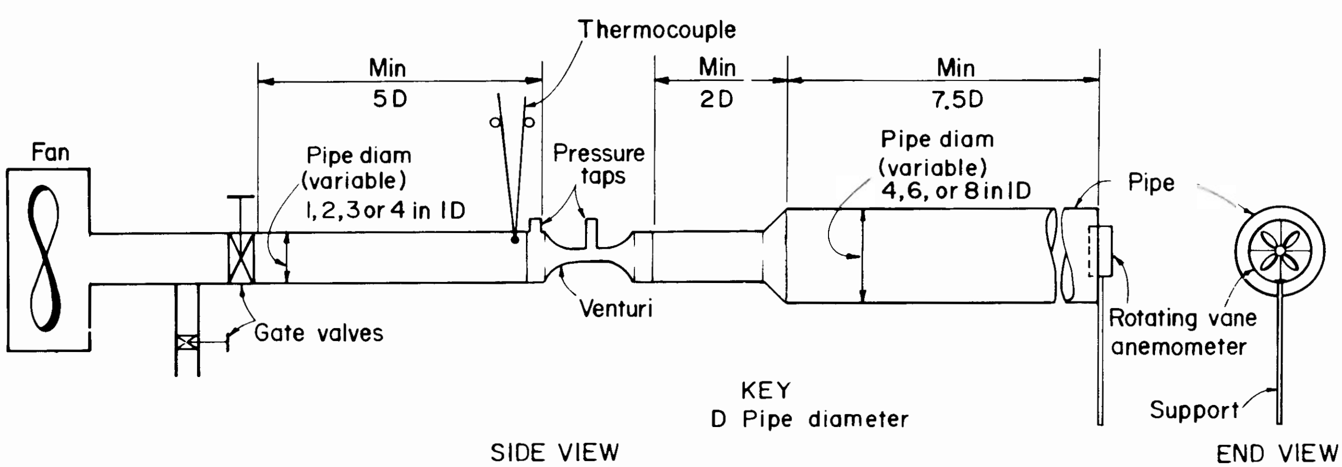

FIGURE 2.—General test setup.

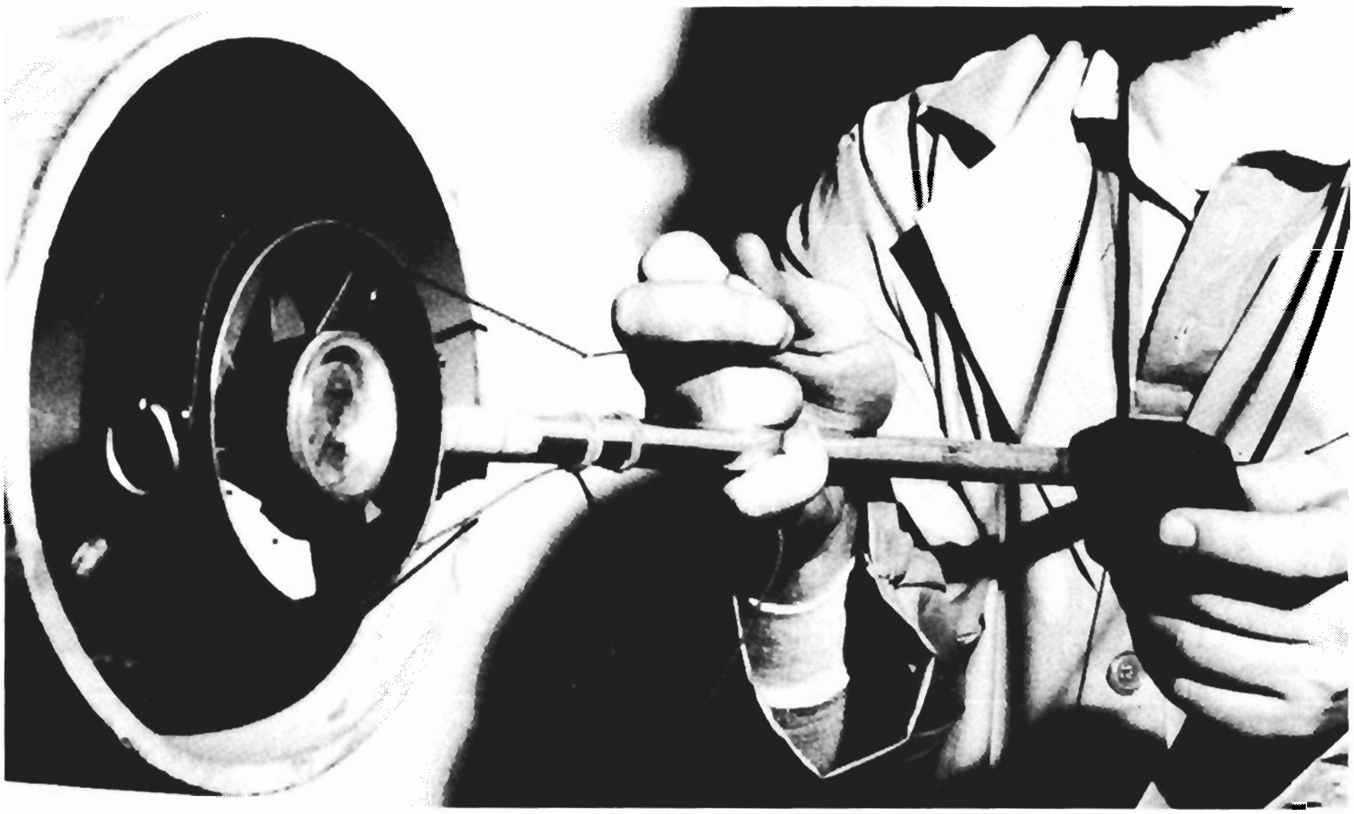

FIGURE 3.—Anemometer measurement at pipe outlet.

FIGURE 4.—Anemometer measurement at 4-in pipe outlet.

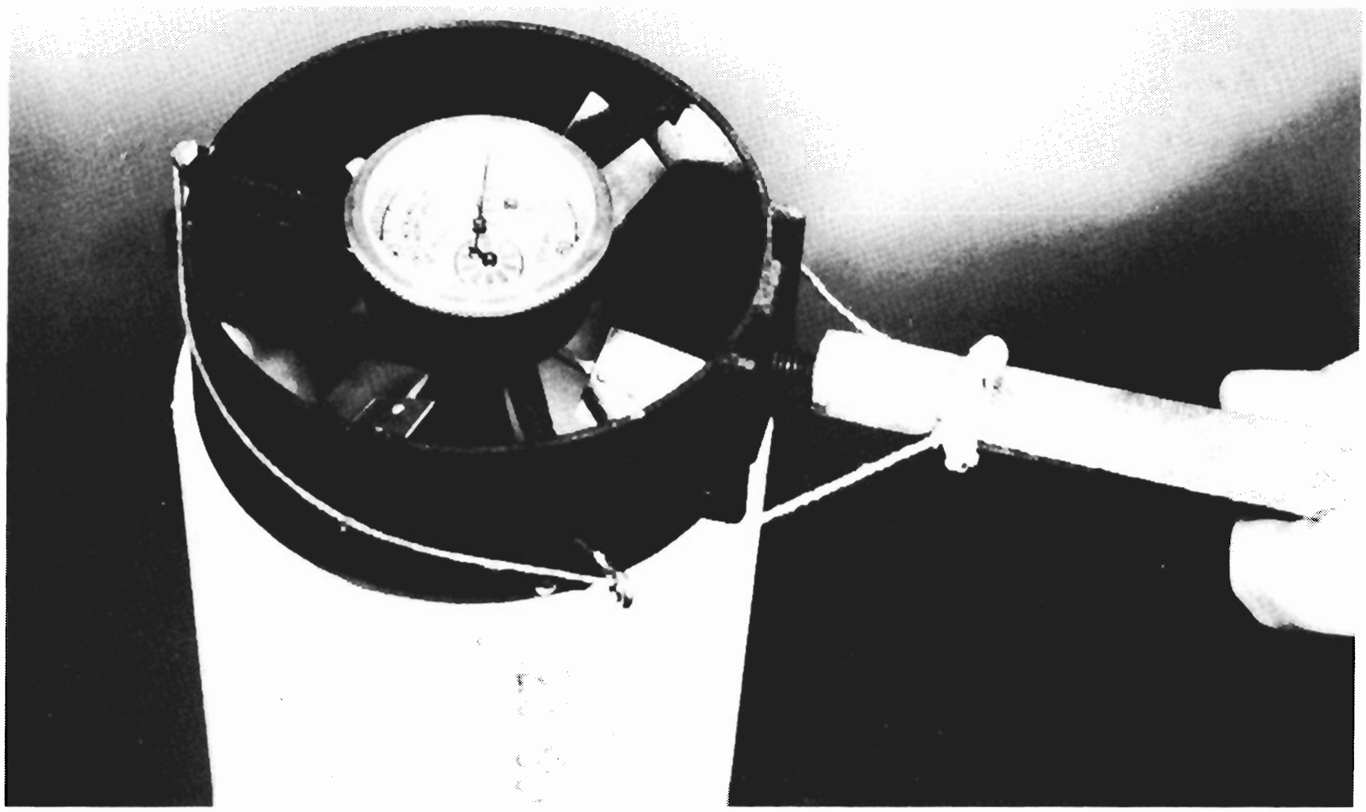

FIGURE 5.—Vertical upward flows.

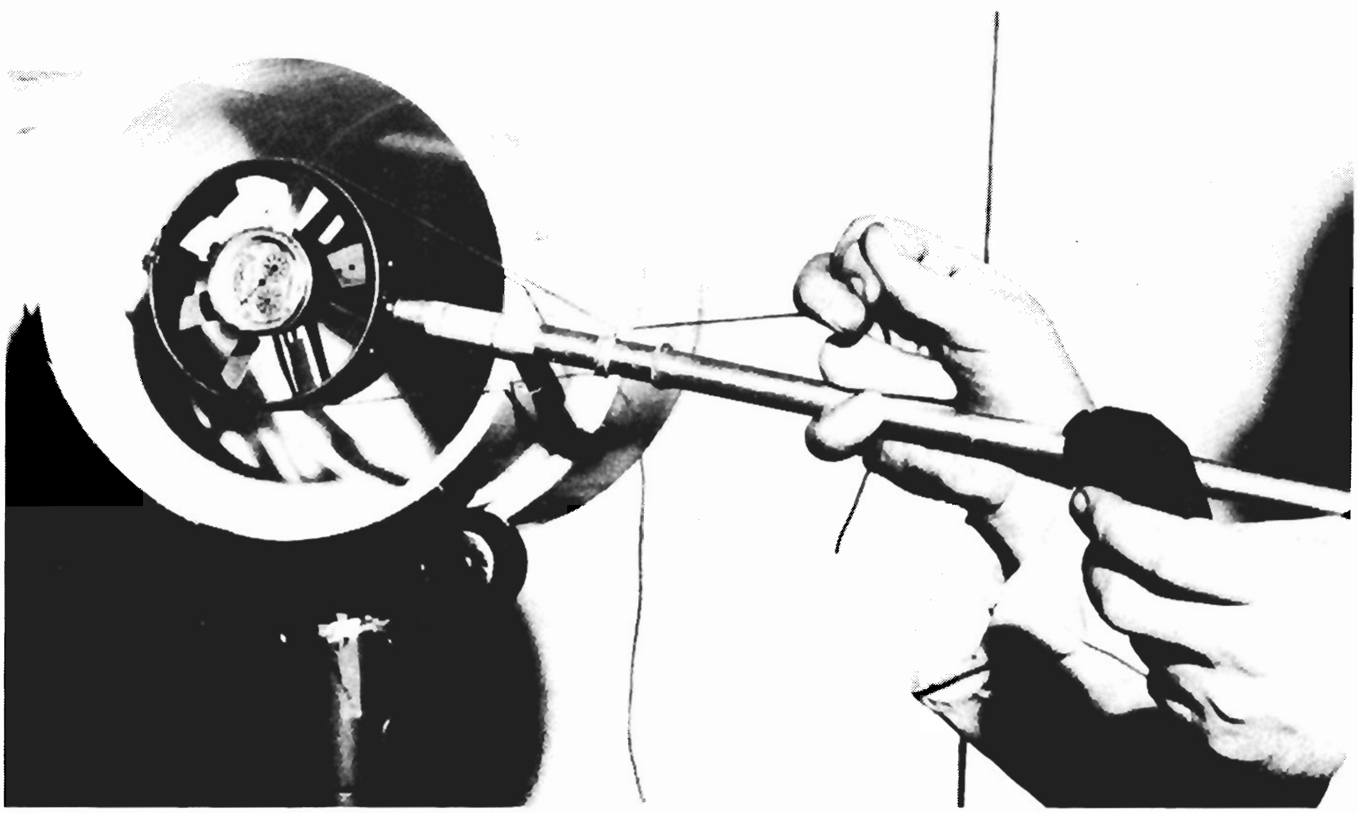

FIGURE 6.—Anemometer measurements closer than 7.5 pipe diameters from an elbow.

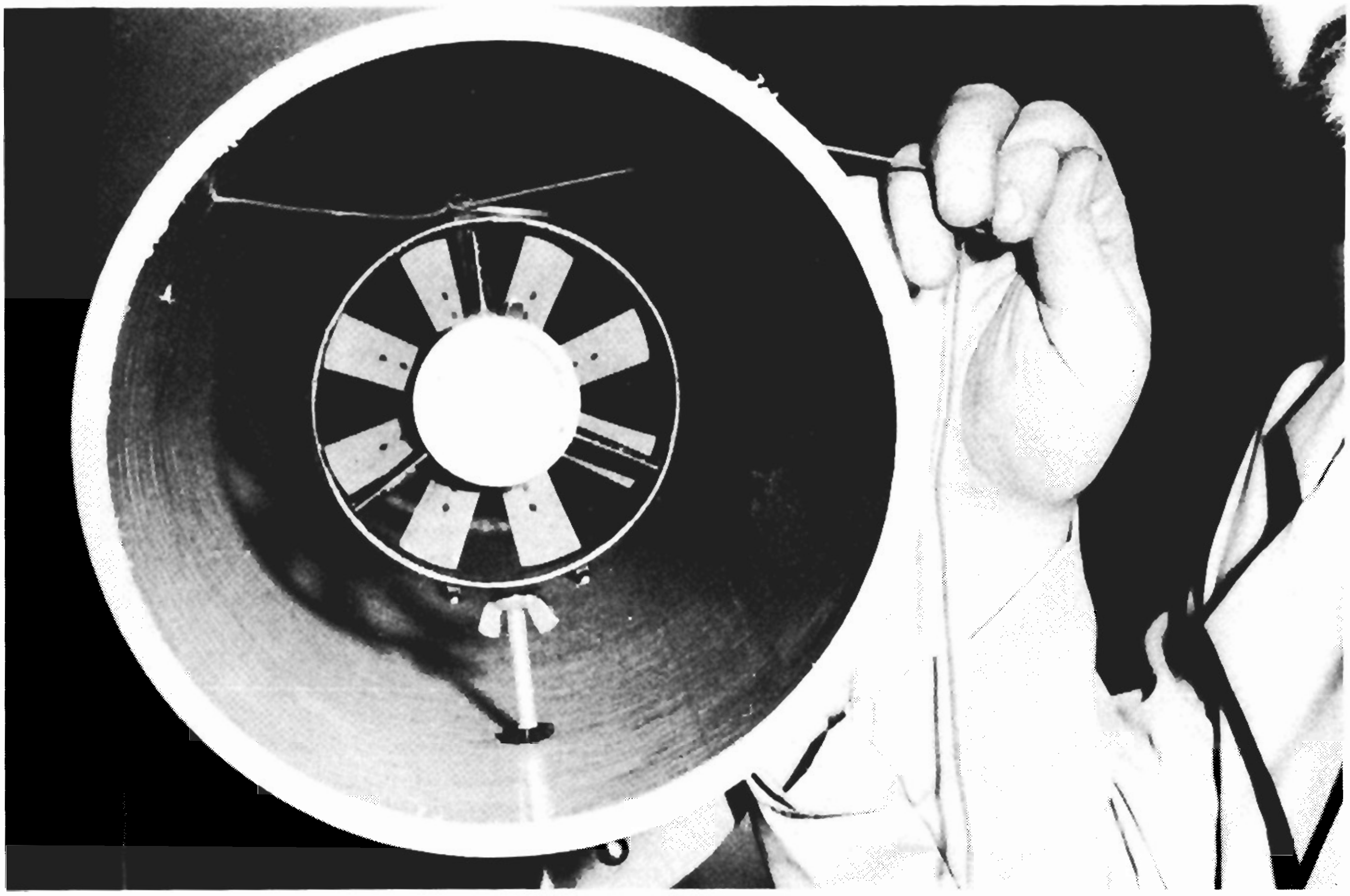

FIGURE 7.—Inserted anemometer.

the end of a pipe are taken closer than 7.5 D from an elbow (fig 6.) or any other factor that causes an abnormal velocity profile in the pipe.

All laboratory tests were conducted in a quiescent environment. In practice, field measurements of gas flow from gob holes are subject to wind velocities that range from a quiescent stage to 15 mi/h (24 km/h) or more. Wind, which blows across the end of the pipe, can cause erroneous anemometer readings. Consequently, tests were conducted to determine the effect of wind speed on method factors. A fan was used to generate winds ranging from 5 to 15 mi/h (8 to 24 km/h); pipe flows ranged from 175 to 2,900 ft/min (0.9 to 14.7 m/s). The method factors determined under those conditions were then compared with method factors determined in a quiescent environment. Tests were also conducted with the anemometer mounted about 6 in (15 cm) inside the pipe (fig. 7).

DATA ANALYSIS

Table 2 shows that the method factors for horizontal pipe flows from 4-, 6-, and 8-in (10.2-, 15.2-, and 20.3-cm) schedule 40 pipe are 0.68, 0.71, and 0.78, respectively, when the low-speed anemometer is used. Each method factor is subject to an analysis of variance and is shown in terms of a 95-pct confidence limit. This means, for example, that there is a 95-pct certainty that the true method factor lies in the interval 0.68±0.07.

Figure 8 shows that the method factor for 4- to 18-in (10.2- to 45.7-cm) pipe increases with pipe diameter and then remains constant (0.85) for larger pipe sizes. Even for an opening as large as a mine entry, the method factor is 0.85.

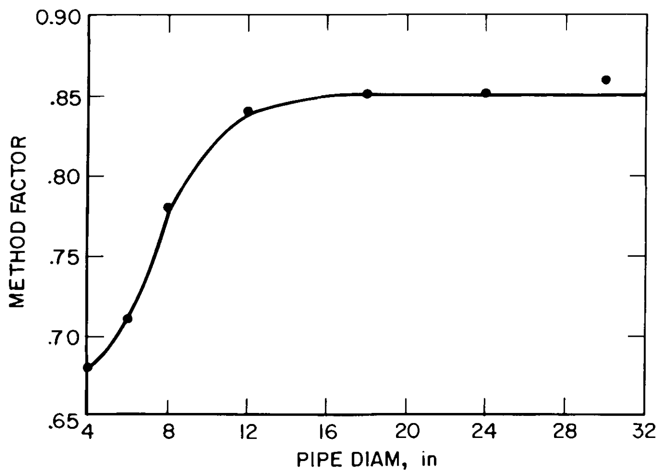

FIGURE 8.—Method factors for 4- to 30-in pipe.

Apparently, the blocking effect of the anemometer is more pronounced on 4- to 18-in (10.2- to 45.7-cm) pipe. For larger openings, the relative size of the anemometer is small in comparison, and the anemometer measures the centerline velocity, which is generally 15 pct greater than the average velocity.

A high-speed anemometer (200 to 10,000 ft/min [1 to 50.8 m/s]) generally has four vanes, whereas a low-speed anemometer (30 to 5,000 ft/min [0.15 to 25.4 m/s]) generally has eight vanes. A blocking effect is created when using an anemometer to measure flows in small diameter pipes, which causes the registered velocities to be erroneously high. Table 3 shows that the method factor for a 4-in (1.6-cm) pipe is 0.78 when a high-speed anemometer is used and 0.68 when a low-speed anemometer is used. Apparently, the larger number of vanes causes the low-speed anemometer to present a greater blocking effect or restriction to flow than the high-speed anemometer; therefore, the low-speed anemometer registered readings are much higher than the high-speed anemometer readings. Consequently, the registered readings for a low-speed anemometer must be multiplied by a smaller method factor to obtain the true average velocity. In experiments involving inlet flows into 12- to 24-in (30.5- to 61.0-cm) tubing, no substantial differences in method factors were noted between high- and low-speed anemometers (7). Apparently, the difference in vane configuration has no effect on the method factor for the larger diameter ducts.

On most occasions, anemometers are calibrated and used with the plane of vane rotation in the vertical. For flows from vertical stacks, though, the plane of vane rotation is horizontal when velocity measurements are made. Table 3 shows a difference of 0.02 between method factor for horizontal and vertical flow from 4-in (10.2-cm) pipe. However, a statistical analysis comparing the two method factors showed that this difference of 0.02 is not significant at the 95-pct probability limit.

TABLE 2. - Method factors for centerline Biran-type anemometer (low-speed) measurement taken at horizontal pipe outlets

Pipe diam, in	Velocity range, ft/min	Mean method factor	95-pct confidence limit
4.........	100-5,000	0.68	±0.07
6.........	100-5,000	.71	±.06
8.........	100-3,500	.78	±.05

TABLE 3. - Method factors for 4-in pipe

	Velocity range, ft/min	Mean method factor	95-pct confidence limit
High-speed............	4,000-10,000	0.78	±0.03
Low-speed:			
Horizontal flow.......	100- 5,000	.68	±.07
Vertical flow.........	100- 5,000	.70	±.08

Table 4 shows that anemometer measurements can be taken closer than 7.5 pipe diameters (7.5 D) from an elbow or any other factor that causes a nonuniform velocity profile in a pipe. For 4-in pipe, velocity measurements as close as 1 D from the disturbance differ from those made at 7.5 D by only about 2 pct. For 6- and 8-in (15.2- and 20.3-cm) pipe, measurements should not be made closer than 3 and 5 D, respectively.

Table 5 shows that wind speed does affect measurements of flow from the end of a pipe. In general, tests on an 8-in (20.3-cm) pipe show that the measured velocity tends to be less when a 15 mi/h (24 km/h) wind blows across the pipe compared with velocity measurements in a quiescent environment. As the velocity of pipe flow increases, the effect of wind on measurement of velocity diminishes. The effects of wind can be eliminated by mounting the anemometer inside the pipe (fig. 7). Table 6 shows that except for very low velocities [100 ft/min (0.51 m/s)], wind has a negligible effect on velocity measurements when the anemometer is mounted inside the pipe a short distance.

TABLE 4. - Effects of an elbow on downstream velocity measurements

Velocity at 7.5 D, ft/min	Difference, pct		
	1 D	3 D	5 D
	4-in PIPE		
500	2	3	1
1,000	2	3	0
1,500	2	3	1
2,000	2	3	1
2,500	1	3	1
	6-in PIPE		
500	4	1	1
1,000	4	2	1
1,500	7	2	0
2,000	7	2	0
	8-in PIPE		
500	10	10	0
1,000	8	8	0
1,500	6	6	1
2,000	4	6	1

D = Pipe diameter.

TABLE 5. - Effects of a 15-mi/h wind speed on flow measurements at pipe outlet

Anemometer measurement, (ft/min), at wind speed of--		Change, pct
0 mi/h	15 mi/h	
180	180	0
240	210	13
360	310	14
560	520	7
750	700	7
1,000	920	8
1,280	1,200	6
1,490	1,430	4
1,750	1,650	6
1,950	1,910	2
2,260	2,180	3
2,900	2,860	1

TABLE 6. - Effects of a 15-mi/h wind speed on an anemometer mounted inside the pipe

Anemometer measurement, (ft/min), at wind speed of--		Change, pct
0 mi/h	15 mi/h	
120	140	17
200	200	0
300	300	0
500	500	0
1,000	1,000	0
1,500	1,500	0
2,000	2,000	0

SUMMARY AND CONCLUSIONS

Method factors for 4-, 6-, and 8-in (10.2-, 15.2-, and 20.3-cm) pipe are 0.68, 0.71, and 0.78 respectively, when the flow velocity at the discharge end ranges from 30 to 5,000 ft/min (0.15 to 25.4 m/s). The method factors for larger pipe sizes approach 0.85, which is also the value of the method factor for a mine entry.

Although the anemometer is calibrated and used with the plane of vane rotation in the vertical, no significant difference in method factors is observed when the anenometer is used to measure vertical flows (plane of vane rotation in the horizontal).

Tests on an 8-in (20.3-cm) pipe show that the measured velocity tends to be less when a 15 mi/h (24 km/h) wind blows across the pipe compared with velocity measurements in a quiescent environment. Wind effects tend to diminish as pipe flow velocity increases. Wind effects on anemometer measurements can be eliminated by mounting the anemometer a short distance inside the pipe.

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